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CORAL REEFS OF THE LOUISIADE ARCHIPELAGO

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The Louisiade archipelago, consisting of four medium-sized and many small islands east of New Guinea, is well represented on British Admiralty chart 2124 on a scale of about 1:280,000; chart 1477 shows part of the archipelago in greater detail on a scale of about 1:140,000. According to brief accounts by Macgillivray,[1] Thomson,[2] and Maitland,[3] the chief islands are composed of steeply inclined and deeply eroded schists and slates, traversed by quartz veins; they are evidently parts of the mountain range that extends for hundreds of miles along the northern coast of New Guinea, from which they have been separated by strong subsidence after having been eroded to about their present form. The largest island is Tagula, 30 miles in length east-west along the trend of its schists, and 8 or 9 miles in width; it has an embayed shore line and rises in 10 summits to heights of from 1330 to 2645 feet. Near by is the Calvados chain of satellite islands, which begins about 7 miles north of the middle of Tagula and extends 70 miles westward; it includes more than a score of members, the largest having a length of 11 miles and a height of 1110 feet. Tagula and its chain of satellites are enclosed by a superb barrier reef, the irregularly oval circuit of which measures 112 miles in east-west diameter by about 30 miles north-south; it is unquestionably one of the finest reefs of its kind in the whole Pacific.

The smaller islands of Rossel to the east and Deboyne to the northwest of Tagula are also surrounded by sea-level reefs, partly as fringes but mostly barriers. Misima, north of Deboyne, measuring 22 by 10 miles and reaching 3500 feet in height, is peculiar in having no sea-level reefs and in descending rapidly into deep water, altho it is terraced by unconformable reefs at various altitudes. It has therefore suffered a recent uplift after having previously taken part in the subsidence which characterizes the other islands; but its subsidence must have been more rapid than theirs, as it has no widely developed barrier-reef lagoon floor, either near present sea level or above or below it.

The Tagula barrier reef and its great lagoon merit special attention from the evidence that they give regarding the verity of certain coral-reef theories. The reef is best developed around the southeastern or windward half of its great oval circuit, where it is interrupted by only 4 passes in a curved distance of 110 miles, and where the reef flat has a width of 2 or 3 miles. The northwestern or leeward half of the barrier is strikingly discontinuous and consists in part of small patches, but more commonly of atoll-like loops and rings, 36 in number, from one to 5 miles in diameter, enclosing little lagoons from 10 to 17 fathoms in depth. The loops and rings of this half of the circuit are separated by as many passages, from $^1/_4$ to 3 miles wide and from 15 to 35 fathoms deep. But the most remarkable features of this part of the barrier are the small or minute but high islands, here to be referred to as outposts, which rise in 22 of the reef loops. The largest of them is only 4 miles in diameter; their heights vary from 40 to 530 feet. Some of them appear to consist of schist, judging by their trends; but according to Maitland some of the others are volcanic and a few are made of limestone. As elements of a barrier reef, these small but high outpost islands are so exceptional as to be almost unique.

The great Tagula lagoon is divided by the Calvados chain of satellite islands into a smaller northern and a larger southern compartment; the northern compartment is of triangular outline, with its base along the dividing chain and its vertex about 10 miles away at the most northern point of the reef; it occupies about $^1/_6$ of the entire reef-enclosed space, which must approach 2000 square miles in total area. The southern compartment measures 20 miles across, and extends east-west along the whole 112 miles of the lagoon length; it occupies about $^4/_6$ of the enclosed area; the remaining $^1/_6$ is taken by Tagula and the satellite islands. The greater part of the lagoon floor in both compartments is a gently undulating plain usually from 25 to 35 fathoms in depth. The depth of the southern compartment increases gradually for a moderate distance from the broad enclosing reef, and more rapidly from the islands of the Calvados chain. The greatest depths, 46 fathoms in the southern or windward compartment and 49 fathoms in the northern or leeward compartment, are in both cases found much nearer the dividing island chain than the outer barrier reef. The exterior slopes of the reef fall off rapidly into deep water; a few soundings show depths of over 600 fathoms two miles from the reef on the west and northwest.

A correct theory of the Louisiade reefs must take account of the great subsidence that the islands have suffered. It would therefore appear that the present sea-level reefs should be regarded as the successors of a long-lived series of upgrowing reefs which have been formed, essentially according to Darwin's theory, by more or less intermittent upgrowth from earlier shore lines of the subsiding mountainous islands. It is probable that where the island slopes were very steep, the reefs, presumably inclining inwards as they grew up, remained attached to the shore as fringes; conversely, where the island slopes were gentler or where low slopes have been broadly submerged, the reefs now form offshore barriers. During the upgrowth of the reefs, some of their detritus must have been swept seaward, to form the submarine talus that descends into deep water; the rest must have been swept into the lagoons, where, reenforced by local organic detritus and probably in smaller measure by detritus from the islands, it appears to have aggraded the "moats" between the reefs and the islands.

It thus seems that the formation of the great undermass of the Louisiade reefs, and especially of the Tagula reef, may well have been consistent with the conditions and processes of Darwin's theory. It should be added that the evidence for the strong subsidence of the Louisiade islands is, in view of their constitution, much more direct than that furnished for the similar subsidence of most reef-encircled volcanic islands in the central Pacific; and that this well certified subsidence of the foundations on which the Louisiade reef-masses have been built up gives immensely greater support for Darwin's theory than is afforded by the atolls of the open Pacific, where the occurrence of subsidence is indicated only by indirect evidence. It remains to inquire whether the Louisiade sea-level reefs, which surmount the great undermass, accord with or contradict other coral-reef theories, especially the newly framed Glacial-control theory of sea-level reefs. This theory was proposed more particularly to account for the atolls and barrier reefs of the supposedly quiescent central Pacific than for the barrier reefs of much disturbed regions like the Louisiade archipelago: nevertheless the Tagula reef in particular affords critical evidence against that theory, as will be made clear by the following considerations.

The Glacial-control theory appears to be based on the conviction that it is the smooth lagoon floors rather than their enclosing reefs which are most in need of explanation, and that the bathymetric relation of the lagoon floors to the level of the ocean reached by the enclosing reefs is normally so nearly constant in all the coral seas that their explanation by Darwin's theory in terms of reef upgrowth and lagoon aggradation on subsiding foundations of irregular form is impossible. A long period of nearly perfect stability of the mid-ocean floor is therefore assumed, altho instability is admitted for islands in the southwestern Pacific; and instead of postulating that lagoon floors represent "moats" that have been heavily aggraded behind the upgrowing reefs during the subsidence of their foundations, a series of ingenious suppositions is invented, of which the chief are: that during Preglacial time many still-standing islands, more or less reef-surrounded, were either worn down to low relief by subaerial erosion or cut down to shallow platforms by marine abrasion; that during the Glacial epochs of the Glacial period the ocean surface was lowered by about 35 fathoms by the withdrawal of water to form continental ice sheets; that the surface waters of the ocean were then so chilled as to kill or greatly weaken reef-building organisms; that islands were then attacked by the waves, which cut low-level benches around them if they were high, or if they were low completely truncated them in platforms at a depth of 35 to 40 fathoms below normal sea level; that as the waters warmed and rose reefs grew up on the margins of the benches and platforms, whereupon the lagoons behind them were moderately aggraded; and that the thickness of the aggrading deposits is greater, and consequently the lagoon depth is less in small than in large lagoons, because the detritus supplied from a linear front-foot of a reef has a smaller interior sector to aggrade in a small lagoon than in a large one. In brief, the long continued stability of reef foundations and the abrasion of sub-lagoon platforms upon them are leading factors of the Glacial-control theory.

It should be noted here that neither the stability of reef foundations nor the abrasion of sub-lagoon platforms is proved by any direct evidence; both of these leading factors are, like the subsidence of atoll foundations in Darwin's theory, assumed because they are thought to be necessary for the explanation of observed facts; and both assumptions are believed to be true because of the apparent success of the explanation that they provide. Hence if it be shown, even in a single instance, that a lagoon floor of typical form and depth has been produced around an island which provides independent evidence contradictory to stability and abrasion and which demands strong subsidence, the fundamental assumptions of the Glacial-control theory will be seriously invalidated.

The bearing of Tagula reef and lagoon on the Glacial-control theory may now be apprehended. Tagula is, as has already been shown, not in a region of long continued and nearly perfect stability, but in one of marked instability; and as will next be shown it has not suffered abrasion by the lowered ocean; yet its lagoon floor is smooth and of a depth accordant with that of other large lagoons in various parts of the Pacific. Hence long continued stability and extensive low-level abrasion are not essential factors in the production of this fine example of a barrier-reef lagoon floor. But if these factors are not essential in Tagula, they should not be regarded as essential anywhere else; and their adoption as the leading postulates of the Glacial-control theory is therefore unnecessary; flatness of lagoon floors and their accordant depths may be explaned elsewhere as well as in Tagula as the result of long continued aggradation on subsiding foundations of uneven surface.

The evidence that Tagula has not suffered abrasion by the low Glacial ocean, and hence that the reef-building organisms around Tagula were not seriously weakened by the lowered temperatures of the lowered ocean in the Glacial epochs, is found in partly in the absence of charted cliffs on the shores of the main island where the barrier reef becomes a fringe, partly in the absence of similar cliffs on the exposed sides of the satellite islands at either end of the Calvados chain where it approaches the barrier reef, and partly in the presence of the outpost islands in the barrier-reef loops around the northern lagoon compartment.

As to the first line of evidence based on the absence of cliffs on Tagula: If abrasion by the lowered ocean had operated long enough to cut a platform 10 or 20 miles wide beneath the present floor of the southern compartment, it ought at the same time to have cut spur-end cliffs on the north shore of the main island, where the defending reef is a fringe only half a mile wide; and these cliffs ought still to show the upper part of their faces as plunging cliffs, now that the ocean has resumed its normal level; but the charts show no such cliffs.

The second line of evidence based on the absence of cliffs on the Calvados islands is similarly argued. It may be added that the absence of cliffs at these significant points on the charts of the Louisiade islands does not appear to be due to poor charting; for on the coast of Misima, where Maitland observed the white limestone scarps of elevated reefs, the charts clearly show a shore cliff, and a legend is printed along it: "Cliffs 100 feet high."

As to the third line of evidence: The little outpost islands are so numerous in the Tagula barrier-reef loops around the northern lagoon compartment and around the western part of the southern compartment that it seems unreasonable to believe the waves of the lowered Glacial ocean could have cut their way behind the outposts efficiently enough to abrade a platform 10 miles in width. Not only so, the outpost islands show no sign of being clift on their outer sides. One of them, Utian, a miles across and 480 feet high, is reported by Maitland to consist of volcanic rocks; but it is not a young volcanic cone built up in Postglacial time, for the chart shows it to have well dissected form, with three slender points enclosing two small bays turned toward the outer ocean; yet the points are not cut back in plunging cliffs. Another outpost not far away is said by the same observer to consist of limestone; this island cannot have been made and elevated since an assumed platform was abraded, for the height of the island, 530 feet, is so great that, in such case, the platform thereabouts ought to be more or less emerged; and it cannot have been made and raised before the platform was cut, for in such case the limestone ought to have been consumed by the waves that cut the platform.

The small outpost islands of the Tagula barrier reef therefore give strong confirmation of the evidence against abrasion derived from the absence of plunging cliffs on the north side of the main islands and on the terminal members of the Calvados chain. But if the northern compartment of the Tagula lagoon, which is alone as large as many an atoll, is thus shown not to be underlaid by an abraded platform, there is no sufficient reason for thinking that the southern compartment or indeed any other barrier reef or atoll lagoon in the whole Pacific has any such smoothly prepared foundation. Surely, if the flatness of the floor and its normal depth in both compartments of the Tagula lagoon have been brought about in a region of instability and without the aid of abrasion in furnishing a smooth sub-lagoon platform, there is no sufficient reason for assuming that other flat lagoon floors of ordinary depth can have been prepared only on smooth platforms abraded at a standard depth across still-standing islands. It is possible that the Glacial lowering of the ocean surface by a moderate amount may have contributed in a manner that I have suggested elsewhere,[4] to the production of many lagoon floors 30 or 40 fathoms in depth; but Glacial changes of ocean level do not seem otherwise to have left recognizable marks of their occurrence in the Louisiade archipelago. Crustal deformation has been dominant; and the great changes of shore lines thus determined appear to have been merely played upon by the inferred oscillations of ocean level during the Glacial period.

This discussion is believed to show that, apart from such changes of ocean level as are inherently probable altho they are not well known either in amount or in effects, the assumptions of the Glacial-control theory are not applicable in the production of Tagula reef and lagoon floor; and hence we may fairly conclude that these assumptions are not essential to the production of similar reefs and lagoon floors elsewhere. This argument, in which the evidence furnished by one outspoken witness for Darwin's theory and against the Glacial-control theory is given wide application, would not be valid if other witnesses were equally outspoken elsewhere against Darwin's theory and for the Glacial-control theory; but such is not the case. It must be remembered that the two main postulates of the Glacial-control theory, namely, long continued stability of reef foundations in the mid-Pacific and the abrasion of sub-lagoon platforms by the lowered Glacial ocean, are not based on direct evidence but are assumed because they are supposed to be necessary for the explanation of smooth lagoon floors of standard depths. Not a single example of an abraded platform has been discovered under recently uplifted reefs; and a good number of mid-Pacific islands which have a decipherable recent history are found not to have been long stable but to have suffered various changes of level. In other words, where other outspoken witnesses are found, their testimony is, like that of Tagula, for Darwin's theory of upgrowing reefs on subsiding foundations of whatever shape. A good number of examples of this kind could be adduced if space permitted.

But although the inhibition of reef growth and the resulting abrasion of low-level platforms by the Glacial ocean thus appear to be excluded from the greater part of the coral seas, it is highly probable that reef-building organisms may have been weakened or killed and that abrasion of platforms may have taken place around islands near the margin of the coral seas; and at least some of those islands ought now to show plunging cliffs in evidence of their possession of submerged platforms; but even there the islands need not have been stable. This aspect of the coral-reef problem is examined in an essay submitted to the Geological Society of America for publication in its Bulletin.

The foregoing discussion will be presented in greater detail in the Annals of the Association of American Geographers.

[1] J. Macgillivray, *Narrative of the Voyage of H. M. S. Rattlesnake*, London, 1852. 2 vols. See i, 182; ii, 72.

[2] B. H. Thomson, "New Guinea: Narrative of an Exploring Expedition to the Louisiade and D'Entrecasteaux Islands, "*Proc. Roy. Geogr. Soc.*, **11**, 1889 (525–542).

[3] A. G. Maitland, "Geological Observations in British New Guinea," *Queensland Geol. Surv. Pub.*, **85**, 1892. "Salient Geological Features of New Guinea," *Journ. W. Austral. N. H. Soc.*, **2**, 1905 (32–56).

[4] "Problems Associated with the Study of Coral Reef," *Sci. Monthly*, **2**, 1916 (565).

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*EXPERIMENTS WITH THE VACUUM GRAVITATION NEEDLE**

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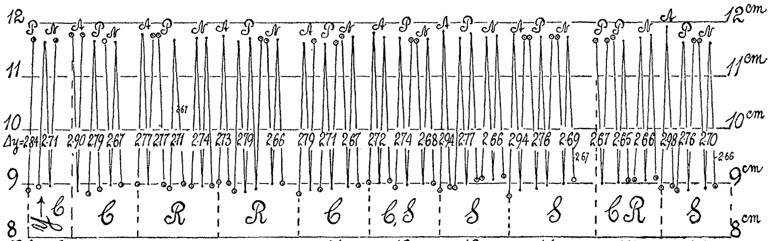
1. *Apparatus.*—At the end of the previous summer's experiments, a form of apparatus was installed capable of exhaustion and containing a gravitation needle made of wires as thin as possible (bronze, .24 mm. in diameter) compatibly with the lead weights, m, at the ends. The object of this was to diminish the radiation effect to an inferior limit, always remembering that the lateral area of the shots m is necessarily in presence. The narrow case was a rectangle of brass with reentrant sides, into which plates of thick glass could be sealed with cement free from air leakage.



Each attracting weight M had a mounting quite independent of the case and could easily be moved between stops from one side to the other of it by a crank-like arrangement.

The half silver method of reading the deflections of the needle and other details were retained, with the scale distance, $L = 447.5$ cm.

The masses of the attracted lead balls at the end of the filamentary needle were $m = .6295$ grams each, though the quartz fibre would have been strong enough to hold a larger mass to advantage. The distances R of the